Cardiac Operations Under Direct Vision

Experience with Extracorporeal Oxygenation of the Blood

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• **A heart-lung machine capable of oxygenating the blood and maintaining normal pressures during cardiopulmonary by-pass was used in 11 cases in which cardiac operations with the heart under direct vision were carried out. The first patient died. Improvements then were made in the machine and it was used in ten additional operations. One of the ten patients died, 18 hours postoperatively, of cardiac tamponade. Since then six more patients have been operated upon with no complications.**

IN THE MIDDLE 1930's Gibbon of Philadelphia began work on an apparatus which would be capable of performing the functions of the heart and lungs. He felt that this would enable surgeons to operate upon intracardiac anomalies under direct vision—open heart operation—in a relatively dry, bloodless field while the brain, myocardium, liver, kidneys and other tissues received adequate flows of oxygenated blood. In 1953, after many years of research, Gibbon reported the first successful operation on the heart of a human subject with the operative field visible and a heart-lung machine oxygenating the blood. The operation consisted of closing an atrial septal defect. In 1954, Senning and Crafoord in Sweden successfully removed a pseudomyxoma of the left atrium. In March, 1955, Kirklin of the Mayo Clinic began to perform operations in which a heart-lung machine of the Gibbon type was used for extracorporeal circulation.

At about the same time Lillehei of Minneapolis started a series of direct-vision intracardiac operations in which controlled cross circulation was used. He soon abandoned cross circulation for the DeWall bubble oxygenator.

At present, there are only two practical methods of oxygenating the blood; one is spreading the blood in a thin film in an atmosphere of oxygen, and the other is mixing bubbles of oxygen in the blood. Disadvantages of the bubble oxygenators are that they cannot maintain sufficient oxygenation for adequate flow, the complete removal of bubbles is difficult and the method destroys many of the constituents necessary for clotting of the blood.

The authors of this communication have used bubble oxygenators, hypothermia, reservoir perfusion and homologous lung oxygenators and have turned away from them as it seemed that the most promising approach to open heart operations was offered by extracorporeal apparatus using the filming technique. Two of us (Kay and Anderson) developed a pump oxygenator apparatus (Figure 1) from three years of research work in which more than 300 experimental operations employing total cardiac by-pass were carried out.

The pump oxygenator is run in the following manner: Blood is returned by gravity drainage from the superior and inferior venae cavae to the venous reservoir. It is then pumped by way of a roller pump to the distribution chamber at the top of the oxygenator. From there it flows onto a series of 12 screens which are suspended from the distribution chamber. Ten liters per minute of a mixture made up of 97.5 per cent oxygen and 2.5 per cent carbon dioxide flow into this chamber and oxygenate the blood. The blood passes through a filter and is pumped into the aorta by way of the femoral artery or subclavian artery. The apparatus is capable of oxygenating and delivering an amount of blood equal to normal cardiac output.

Three milligrams of heparin per kilogram of body weight are used to prevent clotting of blood in the apparatus during perfusion. After by-pass is effected, an equal amount of protamine is used for neutralization of the heparin. In experiments on animals undergoing total cardiac by-pass for a half hour to an hour, it was noted that there was 10 to 20 per cent decrease in the platelets and fibrinogen. There was no postoperative clotting difficulty and the animals received the same amount of blood as they would for routine thoracotomy. There was very little destruction of red blood cells during the period of perfusion and the amount of hemolysis in a half hour to an hour of cardiopulmonary by-pass was less than 50 mg. per 100 cc. of blood. Metabolic acidosis did not occur during or after the period of by-pass. The amounts of pyruvic and lactic acids were within normal limits. In the last 12 consecutive

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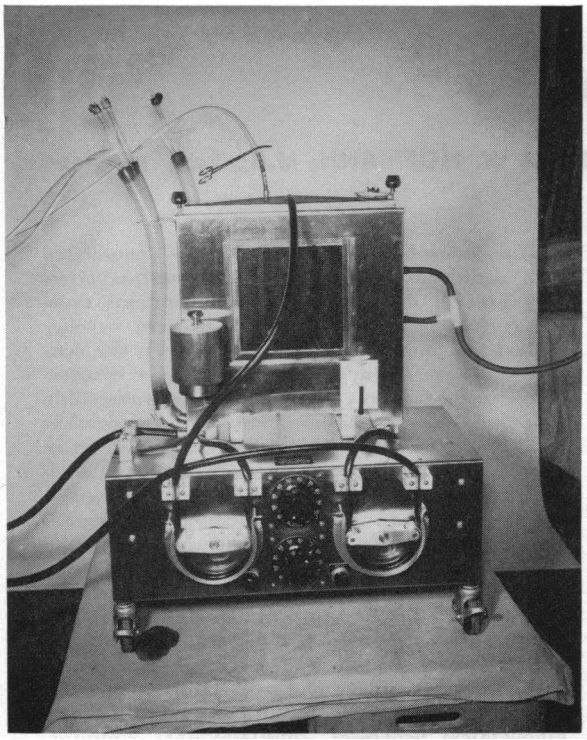

Figure 1.—Kay-Anderson heart-lung machine which consists of two roller pumps and a stationary screen oxygenator. Apparatus is compact and simple to use.

procedures on experimental animals, the heart-lung apparatus was used to by-pass the heart for periods of a half hour to an hour. All the procedures were successful and all the animals survived for long terms. The apparatus then was used clinically. The first procedure was performed on July 12, 1957. The patient was operated upon for a large atrial septal defect and possible ventricular septal defect, and a patent ductus arteriosus. Elective cardioplegia was used, potassium citrate being employed. After 32 minutes of open heart operation, using the heart-lung machine, the machine was stopped and the heart began to beat. However, an effective beat was never restored despite three hours of attempted resuscitation.

Thereupon, further experimentation was performed in the research laboratory and the heart-lung machine was greatly improved and simplified.* It can be sterilized by autoclave. On December 12, 1957, the improved apparatus was used for the first time in an operation on a human subject. The operation consisted of closure of a ventricular septal defect and the patient made an uneventful postoperative recovery. The next two patients, both operated upon for closure of a ventricular septal defect, also did well. In the next case the patient had an atrial septal defect and a ventricular septal defect. Both defects were closed very well. The pericardial sac was closed loosely with four interrupted sutures, as we had done in the previous patients. Postoperatively, the patient was alert and awake but the blood pressure was not adequate, which was believed to be owing to inadequate replacement of blood. Transfusion of blood did not bring about an increase in pressure, however, and the patient died 18 hours postoperatively. At postmortem examination it was observed that, although ample space had been left for blood to leak out of the pericardial sac, enough blood had remained in the sac to form a clot 2 cm. thick around the entire heart, which caused cardiac tamponade and resulted in low blood pressure. The atrial and the ventricular septal defects were both closed very snugly. The ventricular septal defect was located immediately beneath the aortic valve.

Between the foregoing case and the time this report was written, the Kay-Anderson heart-lung machine was used in six additional cases. One patient had a tetralogy of Fallot and a patent ductus arteriosus. The tetralogy of Fallot was completely cured by resecting the infundibular stenosis and suturing the ventricular septal defect. One of the six patients had an atrial septal defect and a valvular pulmonic stenosis. The atrial septal defect was closed and the valvular pulmonic stenosis was incised, under direct vision. The remaining four patients in the series had large ventricular septal defects, which were completely closed. One of these patients also had an anomalous left superior vena cava which drained into the coronary sinus. All of these last six patients have done very well.

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*Constructed for the authors by Corco, Inc., Los Angeles.

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